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LOCAL MASS TRANSFER ALONG THE HEIGHT OF A CYLINDRER SUBMERGED IN A FLUIDIZED BED

A. V. Ostrovskaya and V. N. Korolev

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Results of an experimental study of local coefficients of external mass transfer are presented as a function of the process parameters in a fluidized bed.

Unlike external heat transfer in a fluidized bed, external mass transfer and its dependence on the regime parameters of the medium have been studied inadequately. There are some works [1–4] on experimental investigation of the average rate of mass transfer from the surface of plane, spherical, and cylindrical bodies. Publications on local mass transfer are extremely scanty [3, 5].

The objective of the present study is a thorough investigation of local external mass transfer and its dependence on the process parameters.

Experiments were carried out following the procedure described in [1]. The experimental setup was an apparatus of organic glass with a diameter of 100 mm and a height of the cylindrical part of 240 mm. A cap grid with seven caps was used as a gas header. Monobeds of corundum particles with diameters of 0.12, 0.16, 0.25, 0.32 mm were used as a disperse material. The height of the stationary bed was 230 mm. The bed was fluidized by air that was preheated by an electric heater. The air flow rate was measured with a double diaphragm and a micromanometer.

At the center of the fluidized bed apparatus at a height of 60 mm above the gas distributor grid a specimen was fixed vertically. In the first experimental series the specimen was a cylinder with a diameter of 16 mm composed of ten identical pellets with a height of 10 mm each; nine of them were metal and one was naphthalene. In the experiments the latter was displaced successively along the height of the specimen.

The weight loss of the naphthalene was determined by weighing the specimen before and after the run with an analytical balance, accurate within 0.0001 g. The mass transfer surface area was found by repeated measurements of the diameter and height of the specimen. The duration of an experiment was 30–60 min, depending on the fluidization velocity.

In the determination of the mass transfer coefficient the contribution of adsorption and abrasion to it was neglected, because special studies [1, 3] have shown that abrasion of naphthalene specimens submerged in a fluidized bed and adsorption of naphthalene by particles in the bed at 50–60°C are negligibly small compared to convective mass transfer. Therefore, in our experiments the average temperature of the bed was kept at 55°C. The mass transfer coefficient was calculated from the relation

$$\beta = \frac{\Delta GRT}{FM\tau\,(P_{\text{sur}} - P_0)}\,. \tag{1}$$

The content of naphthalene vapor P_0 in the main flow was zero, and therefore the difference in the partial pressures of naphthalene $(P_{\text{sur}} - P_0) = P_{\text{sur}}$ near the surface of the specimen was found as a function of the temperature of the bed from the formula given in [1]. The error in determination of β from Eq. (1) was within 3%.

The experimental results have revealed nonuniformity of naphthalene sublimation along the cylinder height (Fig. 1, curve 1). The maximum mass transfer was observed in the lower part of the body and at a height of 80

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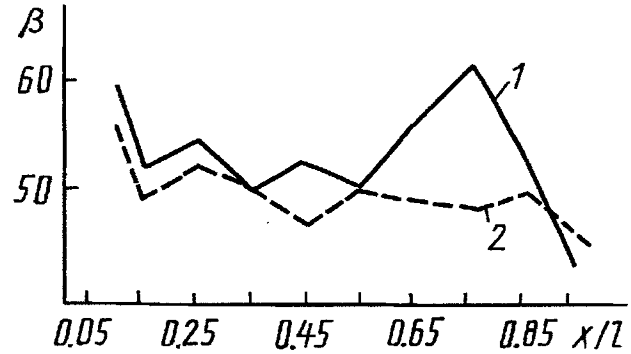


Fig. 1. Comparison of local mass transfer coefficients along the height of the cylinder for the whole specimen (1) and individual pellets (2). β, m/h.

mm from the lower face. The weight loss from the upper pellet was the lowest. Experiments on local external heat transfer [6] have revealed that the heat transfer coefficient also changes along the height of a submerged body although there is no complete analogy between heat and mass transfer processes in a fluidized bed [7].

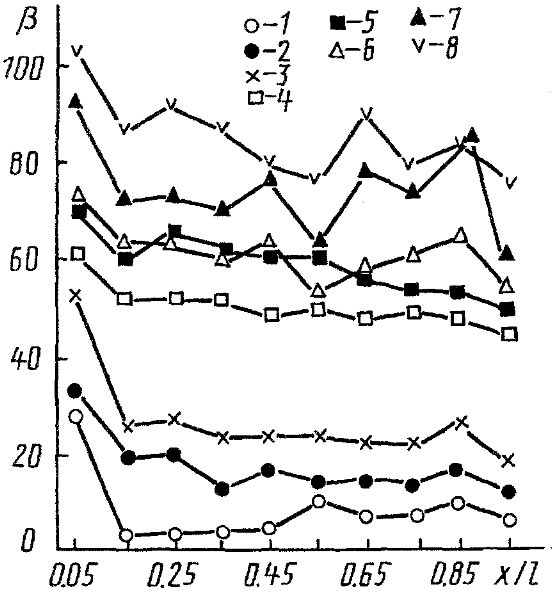
The behavior of the obtained distribution of the mass transfer coefficient along the height of the body depends on the hydrodynamic situation occurring near the surface of the body submerged in the fluidized bed. Under the lower face of the cylinder a gas cavity is formed [6]. When it collapses, the gas flows from under the face with a large velocity, because of which the mass transfer coefficient β increases in the lower part of the cylinder. The gas flowing from under the face of the cylinder forms bubbles that grow in volume as they rise along the vertical surface. Additional fluctuations of the gas velocity and the porosity of the bed are induced at the sites of separation of the bubbles from the cylindrical surface. An intense gas flow drawn into a bubble from the near-wall region of the bed and the appearance of a local fluidization site at the place of separation of a bubble also result in an increase in the local mass transfer. At the upper face of the cylinder a patch of immovable material is formed, which slides down along the cylindrical surface to a certain depth and prevents sublimation of naphthalene. Consequently, the mass transfer coefficient is always lowest in the upper part of the cylinder.

The authors of [5], who determined the mass transfer coefficient of a separate naphthalene strip fused onto a plate, failed to find changes in β for different heights of the location of the strip on the plate. This can probably be explained by the fact that in the experiments of [5] the width of the strip was 40 mm and the mass transfer was the average one rather than the local one in contrast to the present experiments, in which the height of each pellet was 10 mm.

Since under real conditions mass transfer occurs between the bed and a body made completely of one material and submerged in the bed, it can be expected that as the flow moves along the cylindrical surface, an increase in the concentration of the material in the near-wall layer will affect the intensity of the mass transfer process. Therefore, the second experimental series was carried out with a cylinder composed of ten naphthalene pellets.

Experimental results have shown that mass transfer from the lower part of the body remained unchanged (Fig. 1, curve 2); subsequently, β was a virtually monotonic function of the bed height. The numerical values of β over the whole surface (except for the lower pellet) are somewhat lower than those for a single naphthalene section. In the upper part of the cylinder the mass transfer coefficient remained the lowest.

The rate of mass transfer from the cylindrical surface increased with increase in the fluidization number from $W = 1.05$ to $W = 6.0$ (Fig. 2) since the frequency of fluctuations and the porosity of the bed increased in the near-wall zone of the body. The distribution of β along the height of the cylinder changes as well: at $W = 1.05-4.0$ the mass transfer from the first (lower) pellet was 2.5–3.0 times higher than that from the remaining surface, the mass transfer from which remained practically constant (Fig. 2, curves 1–5). As the fluidization number increases $W > 4.0$), mixing of gas in the bed improves, more naphthalene is transferred from the surface into the bulk of the bed, nonuniformity of evaporation of naphthalene from the cylindrical surface increases, and the maximum in



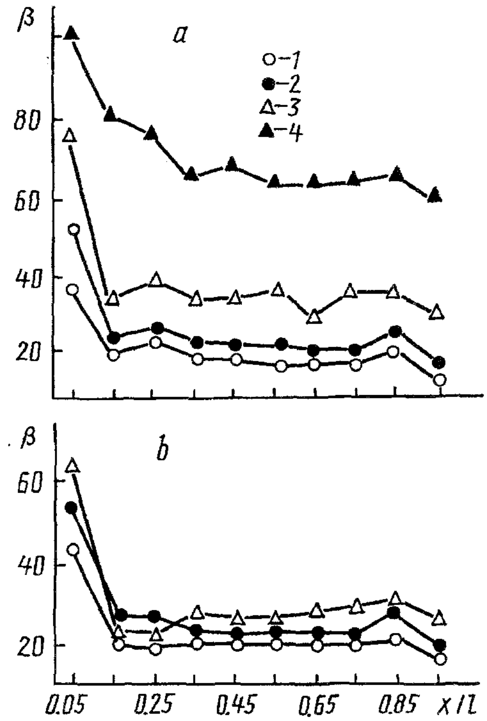


Fig. 2. Plot of the local mass transfer coefficient versus the fluidization number; d_s = 0.16 mm; d_B = 16 mm: 1) W = 1.05; 2) 2.0; 3) 2.5; 4) 3.5; 5) 4.0; 6) 5.0; 7) 5.5; 8) 6.0.

Fig. 3. Plot of the local mass transfer coefficient versus the diameters of the particles (a) and the cylinder (b): W = 2.5; a) D_B = 16 mm: 1) d_s = 0.12 mm, 2) 0.16, 3) 0.25, 4) 0.32; b) d_s = 0.16 mm: 1) d_B = 12 mm, 2) 16, 3) 20.

the upper part of the body becomes more pronounced (Fig. 2, curves 6–8), as in the case with separate naphthalene pellets.

As the diameter of the particles in the bed increases from 0.12 to 0.32 mm at the constant fluidization number W = 2.5, mass transfer from the cylindrical surface is enhanced (Fig. 3a) due to an increase in the velocity of the fluidization agent, and as has been shown above, this increase intensifies filtration mixing of the gas and enhances mass transfer.

Changes in the diameter of the cylinder from 12 to 20 mm do not affect mass transfer substantially, which was also observed in [7]. However, as can be seen from Fig. 3b, β does increase slightly with the diameter of the submerged body. This can probably be ascribed to the fact that an increase in the diameter leads to a decrease in the free volume of the bed and an increase in the air velocity in it (in the determination of the fluidization number the air velocity was calculated on the basis of the free cross section of the apparatus).

Processing of the experimental data obtained gave a dimensionless relation for calculation of the local mass transfer coefficient along the height of the cylinder as a function of the fluidization number W, the Archimedes number, the particle diameter d_s, and the diameter d_B of the submerged body:

$$\mathrm{Sh} = 0.05W^{0.75}\,\mathrm{Ar}^{0.33}\left(\frac{d_s}{x}\right)^{-0.68}\left(\frac{d_@}{x}\right)^{0.45^{*)}}, \tag{2}$$

where W = 1.05–6.0; Ar = 426–3412; $d_s/x = 1.3\cdot10^{-3}$–$6.4\cdot10^{-2}$; d_B/x = 0.13–4.0. The mean square deviation of quantities calculated by formula (2) from experimental data is within ±8%.

In Fig. 4 mass transfer coefficients averaged over the body surface are compared with the equation obtained in [5]. It can be seen that the mass transfer coefficients obtained in the present work are greater than the data of

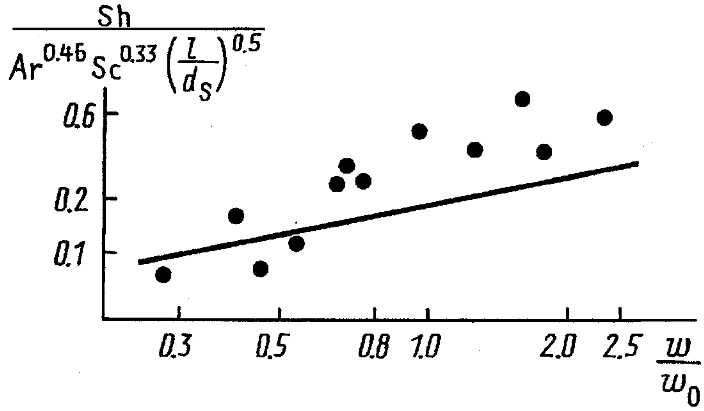


Fig. 4. Comparison of the present experimental results with published data: points show mass transfer coefficients averaged over the cylindrical surface; the line is calculated with the equation of [5].

[5], especially at high gas velocities. This can be ascribed to the fact that in the experiments of [5] plates with a naphthalene layer fused onto one side were used as specimens, while we used cylinders. At low gas velocities ($w/w_0 = 0.3-0.6$) the bed is fluidized uniformly and therefore the mass transfer coefficients β of the plate and the cylinder are almost the same. As the velocity increases, the fluidization becomes nonuniform, gas bubbles arise at one side of the body or the other [6], and consequently the mass transfer coefficients of a plate with one-sided sublimation of naphthalene were less than those of a cylinder, for which this nonuniformity was unimportant.

NOTATION

β, mass transfer coefficient, m/h; W, fluidization number; ΔG, weight loss of naphthalene, kg; R, universal gas constant, J/(kmole·K); F, mass transfer surface, m^2; M, molecular weight of naphthalene, kg/kmole; τ, duration of an experiment; P_{sur}, P_0, partial pressures of naphthalene near the surface and in the main flow, N/m^2; d_s, diameter of the particles, m; d_B, diameter of the submerged body, m; l, total height of the cylinder, m; x, instantaneous coordinate along the height of the cylinder (measured from the lower face), m; w, w_0, operating and optimum velocities of fluidization, m/sec; Ar, Archimedes number; Sh, Sherwood number.

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